STUDIES OF WEATHERING PRODUCTS IN THE LAFAYETTE METEORITE: IMPLICATIONS FOR THE DISTRIBUTION OF WATER ON BOTH EARLY AND RECENT MARS.

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The question of where and when there has been liquid water on Mars is one of the most fundamental problems on the red planet. Photogeological evidence suggests that there has been water flowing on the surface from time to time [1], and some interpretations suggest that there have been oceans on Mars on occasion [2]. In collaboration with D. J. Lindstrom (NASA-JSC) and A. H. Treiman (LPI), the Arizona noble gas mass spectrometry lab has been studying liquid-water-derived weathering products in the martian meteorite Lafayette in an attempt to determine absolute radiometric ages.

Those studies have 1) confirmed that the weathering products in Lafayette are martian, not terrestrial, in origin; 2) demonstrated that there has been liquid water on Mars in the last 1300 Ma, and suggested that this has occurred in the last few hundred Ma; and 3) suggested that this water has been in contact with the martian atmosphere, and hence is near-surface, rather than magmatic, water. Given the fact that most photogeological evidence for liquid water on Mars suggests that it was more prevalent in the distant past, one might then expect that ancient martian meteorites would contain even more evidence for aqueous alteration. Instead, the only ancient martian meteorite known, ALH84001, seems to have been no more altered than Lafayette. In this abstract, we will briefly describe the results of the noble gas isotopic studies, and then point out some of the puzzling implications for early Mars.

Noble gas isotopic studies of martian weathering products: Swindle et al. [3,4] studied samples of "iddingsite" from Lafayette. Iddingsite is a complicated mixture of clays, oxides and ferryhydrites that requires liquid water to form. Microstratigraphic arguments have been used to suggest that these formed on Mars [5,6]. A. H. Treiman separated 16 samples that were analyzed with laser-extraction noble gas mass spectrometry.

The single largest sample (34 mg) was used for analysis of the heavy noble gases, krypton and xenon. Although the signal was only a few times the background level, the results [3] suggested that the iddingsite sample does contain trapped martian atmosphere (Fig. 1). Furthermore, both the Kr/Xe elemental ratio and the $^{129}Xe/^{132}Xe$ isotopic ratio are consistent with the iddingsite being the primary carrier of trapped martian atmospheric noble gases in the nakhlites. On the other hand, the Kr/Xe ratio of the iddingsite (like the bulk nakhlites) is fractionated relative to the martian atmosphere. Drake et al. [7] suggested that this is the result of the iddingsite trapping martian atmosphere from water, which could fractionate Kr from Xe. This, in turn, implies that the water which formed the iddingsite was in communication with the atmosphere. This would not be expected to be true for magmatic water.

Most of the samples were used for ^{40}Ar-^{39}Ar [3] and K-Ar [4] studies. A range in apparent ages, from roughly 100 to 650 Ma, was observed. These demonstrate that the weathering products are not terrestrial. Since Lafayette is 1300 Ma old, the weathering products can be no older than that. The data suggest that they might be much younger. However, it is also possible that they formed from water liberated by the magmatic episode that produced the nakhlites, but were partially degassed, to varying degrees, later.

Implications for early Mars: The fact that there has been liquid water flowing through martian rocks in the last 1300 Ma has several implications for the earlier history of water on Mars. Most obviously, if such a young rock has evidence of aqueous alteration, we might (perhaps naively) expect to see much more of such alteration in a much older rock, but this is not the case for ALH84001. There are some features that are probably the result of secondary alteration at relatively low temperatures [8], but the total abundances of these phases is comparable to that in Lafayette, no more than a few percent. In addition, the alteration seems to have involved CO_2-charged fluids, which produced carbonate, rather than the types of hydrous minerals seen in Lafayette.

In part, the relative lack of aqueous alteration features in ALH84001 must be related to the source of the fluid. For the nakhlites, the heavy noble gas data suggests that the water is not magmatic in origin. It could come from either melted permafrost or deeper groundwater [9], released by the effects of either impacts [10] or volcanism. ALH84001 was clearly reheated about 3.9 Ga ago [11], but perhaps it was in a region that was exposed to neither volcanic activity nor large impacts since then.

The lack of extensive aqueous alteration in ALH84001 is also difficult to reconcile with models of a warmer, wetter Mars which had extensive precipitation. It is clear from the shock-metamorphic cataclastic texture of ALH84001 that by ~4.0 Ga, the rock was more porous and more permeable than it was in its pristine igneous state. For the same reason, it was probably more porous and permeable than Lafayette, which has suffered very few shock-metamorphic effects. Consequently, if precipitation was widespread 4.0 Ga ago, it seems that it should have affected ALH84001 at least to the extent that relatively drier conditions affected Lafayette less than 1.3 Ga ago.

Alternatively, if precipitation and subsequent percolation of aqueous fluids have not affected ALH84001, perhaps sapping models for the topographic degradation and valley formation seen in the highlands are more likely [12]. Assuming that a liquid water aquifer fed the sapping process, the lack of aqueous alteration in ALH84001 suggests that the meteorite has not been within the aquifer for at least the last ~4.0 Ga. The bottom of the aquifer is defined by the level in the crust at which self-compaction eliminates porosity, estimated to be about 10 km [9]. The top of the zone in which liquid water is stable is determined by the geothermal gradient. This may have been within a few hundred meters of the surface 4.2 Ga ago [12], but would have rapidly moved deeper, except for local effects.

For meteoritic material to be launched from Mars with escape velocities, it probably has to be relatively close to the surface. At the present time, it is unclear whether or not the igneous cumulate represted by ALH84001 was emplaced at these shallow depths, or whether it was excavated from a deeper level by an impact cratering event and emplaced as impact ejecta at a shallower depth. In either case, it has probably been at a shallow depth for the last ~4.0 Ga. Given its lack of exposure to low-temperature liquid water, this suggests that, whether precipitation or sapping caused the valley networks, there were at least regions of Mars where the near-surface region was dry by ~4.0 Ga ago.

In summary, the 1.3 Ga old Lafayette is as heavily altered as the much older ALH84001, although the alteration of Lafayette seems to have involved more water (and possible lower temperatures) than that of ALH84001. This is hard to reconcile with models that suggest that Mars was wetter in the distant past, unless the era(s) of warm, wet climate or active sapping had largely ended by 4.0 Ga. These differences suggest that the alteration products may not be the result of global processes, but rather of localized geologic and hydrologic domains.

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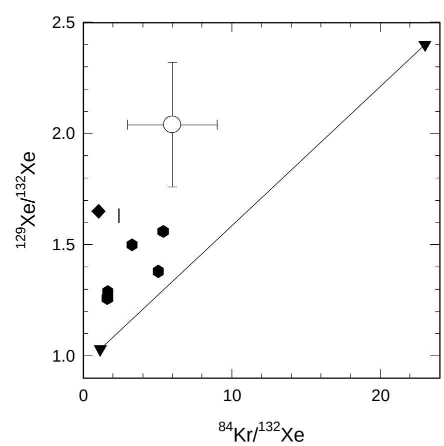

Figure 1: Plot of the $^{129}Xe/^{132}Xe$ isotopic ratio vs. the $^{84}Kr/^{132}Xe$ elemental ratio for various martian meteorites. Most shergottites (not shown) plot along the line connecting the martian atmosphere (upper right, measurement from EETA 79001) with Chassigny (lower left, potentially a sample of volatiles from the interior of Mars). Whole-rock nakhlite meteorites (solid symbols) have elevated $^{129}Xe/^{132}Xe$ ratios suggesting the presence of martian atmosphere, but their low Kr/Xe elemental ratios mean that if they did incorporate atmospheric gas, it was through a process that involved elemental fractionation. The iddingsite sample (open symbol) looks similar to the whole-rock nakhlites, and the absolute abundances in iddingsite are high enough to suggest that it is a major (if not the dominant) site of the atmospheric-like gases in nakhlites.